GATEWAY HOUSE
INDIAN COUNCIL ON GLOBAL RELATIONS

Achieving the Promise of Hydrogen for India and the World

by **Amit Bhandari,** Senior Fellow, Energy, Investment & Connectivity
& **Dr. Chaitanya Giri,** Former Fellow, Space & Ocean Studies

MARCH 2022

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1. Executive Summary

This paper studies and analyses the viability of using green hydrogen as a vehicle fuel and as an industrial gas, the reasons it is necessary to consider, and recommendations for companies, entrepreneurs and policy-makers to enable the use of this clean energy source. The advent of cheap renewable energy has made it possible to produce hydrogen from water by electrolysis, also called green hydrogen. Green hydrogen offers a way to store renewable energy in bulk, not possible otherwise with existing battery technologies. In this role, green hydrogen can serve as a multiplier for renewable electricity.

Interest in green hydrogen has risen in line with environmental concerns and most major economies including India have a hydrogen plan in place. For India, the use of hydrogen in transport offers an additional advantage – reduced import dependence on minerals such as lithium and cobalt, which have unproven and potentially unreliable supply chains.

Based on our study of the hydrogen market, we feel that wider adoption of green hydrogen can be made easier by first using it in existing applications such as petroleum refineries, as a replacement for grey hydrogen (produced from fossil fuels). This approach will ensure that investments made in the production of green hydrogen don't become stranded assets. The use of green hydrogen in vehicles can be pioneered by using it in gated infrastructure such as ports and warehouses, which will not require the creation of a geographically dispersed fuelling infrastructure. Finally, India also needs to enable its vibrant start-up sector, which can come up with new technologies as well as business models by directing risk capital towards innovators working on green hydrogen.

2. Introduction

India's push for alternate and renewable energy like solar, wind, nuclear, and bioenergy, and clean fuels like biofuels, hydrogen, natural gas has two drivers: the need to reduce the country's dependence on imported energy and to reduce its greenhouse-gas emissions to meet its environmental commitments. The country has made substantial progress. At the end of March 2021, renewable energy accounted for almost one quarter of India's installed generation capacity and 11.8% of actual electricity generated during FY21, and it is widely assumed that the trend towards renewable energy is inevitable and permanent.

Table 1. India's Renewable Energy Generation Capacity (in Megawatts)

	Wind	Solar	Total Renewable	Total
FY18	34,046	21,651	69,022	344,002
FY19	35,625	28,180	77,641	356,100
FY20	37,694	34,628	87,027	370,106
FY21	39,247	40,085	94,433	382,151

Source: Central Electricity Authority, India

But several factors belie this expectation. The intermittent nature of renewables will make increasing their share of total energy difficult unless a way is developed to store electricity at grid scale. Also, India's commitment to coal clouds the prospects it can meet its goals for reducing fossil-fuel consumption. And the poor health of electricity-distribution companies raises questions about their capacity to finance the development of major new energy sources on a large scale. Moreover, India does not yet have an ecosystem that would support the widespread use of electric vehicles, and it lacks an independent supply for the critical minerals that help power the vehicles.

Hydrogen may well be the answer. It can be produced as a vehicle fuel from water using electricity generated from renewable sources. It can be stored at a large scale. And it can help India meet its environmental objectives by reducing its dependence on petroleum, a relatively expensive fuel, rather than coal, which is cheaper. If it can be supplied in large quantities to the transport market, renewable energy companies will reduce their financial dependence on bankrupt state electricity boards. And since it can be stored, increased use of hydrogen also can reduce the need for two parallel energy infrastructures, which currently are required because of the intermittent nature of renewable energy.

Is India ready to become a hydrogen economy? Certainly, there is a push in that direction. On August 15, 2021, Prime Minister Modi announced the setting up of the National Green Hydrogen mission, which aims to make India a production hub for green hydrogen.1 India has also joined the Hydrogen Council, and a number of Indian companies and institutions have formed the Hydrogen Association of India.

This paper explores the potential of hydrogen as a clean, alternative fuel and India's opportunity to play an important role, domestically and internationally, in the emergence of a new hydrogen economy. It focuses especially on "green" hydrogen which, because it is produced with renewable energy, is homegrown, scalable and viable.

3. The Emergence Of Hydrogen as a Viable Alternate Fuel

Hydrogen is fast emerging as a leading alternative to fossil fuels both for power generation and, more importantly, as an absolute or blended fuel in the road, rail, aviation and maritime transportation systems.

I. Reasons for Renewed Interest in Hydrogen

India first became interested in hydrogen as a vehicle fuel during the early 2000s, when high petroleum prices prompted a search for alternatives, but the interest receded as oil prices moderated. The current push for hydrogen is being driven by its potential role as a tool for addressing issues that are becoming increasingly evident in the renewable energy industry. Specifically:

- **Intermittency of Renewable Energy:** Solar and wind energy, by their nature, are intermittent. In the absence of grid-scale storage, the high demand for energy during night times can only be met using conventional power. This leads to duplication of energy generation infrastructure. The energy crisis witnessed in Western Europe in August-September 2021 is an example of how renewable energy can fail. Hydrogen can be produced using renewable energy and stored on a large scale, unlike energy storage in the form of lithium-ion batteries. This could help make the supply of energy from renewable sources more regular and make electricity generation infrastructure planning more efficient.
- **The Coal Conundrum:** Using renewable energy to produce hydrogen for use as a vehicle fuel makes renewable power a direct replacement for petroleum, thus helping India achieve its commitment to reduce its consumption of fossil fuels. That goal would be very difficult to achieve by reducing India's use of coal. During the financial year 2020-21 (FY21), coal accounted for approximately 75% of all electricity generated in India, while hydro, renewable and nuclear energy accounted for the rest. Most of the coal used for power generation in India is produced domestically. Coal-fired electricity is the cheapest energy available in the country. During FY20, NTPC Limited, India's largest thermal power generator, received a tariff of Rs. 3.82 per kilowatt-hour (kWh), up from Rs.3.49/kWh for the previous year.[2] Thus, renewable energy currently is competing with the country's cheapest energy source, reducing its financial viability. Using renewable energy to produce hydrogen to fuel vehicles will improve the outlook for renewable power while reducing dependence on India's most expensive energy source, thus addressing energy and environmental concerns simultaneously.
- **Solvency of State Electricity Utilities:** State utilities are the biggest distributors of electricity in India, and therefore the biggest customers of generation utilities. But they are collectively bankrupt. Their Aggregate Technical & Commercial (AT&C) losses in 2018-19 were 22.03% of total power generated (latest available figures). In FY2019, state utilities incurred a collective loss of Rs. 52,838 crores. If renewable energy's biggest customer is bankrupt, it will have trouble raising funds for new investments. Selling hydrogen to fuel vehicles will reduce the dependence of renewable energy companies on bankrupt state utilities and will give them a set of financially solvent customers (oil marketing companies).

- **Barriers to expanding use of electric vehicles generally:** The increasing use of electric vehicles (EVs) can promote the use of renewable energy (to charge EV batteries). But while the NITI Aayog has been aggressive in pushing for electric mobility for India,[3] the results so far have not been encouraging.[4] Under the circumstances, an all-out push for electric vehicles may be counterproductive for India because electric vehicles require minerals such as rare earths, cobalt and lithium, which are not found naturally in India and whose supplies in many cases are controlled by China. Wide adoption of EVs without securing raw materials thus could make a critical sector of the economy dependent on China. Using hydrogen in fuel cells or internal-combustion engines can reduce or eliminate the need for minerals such as lithium, cobalt and rare earths.
- The challenge of switching heavy trucks to clean energy. About 40% of all oil consumed in India is in the form of diesel, which is mostly burnt by heavy trucks. At this time, lithium-based batteries for heavy-duty trucks are extremely inefficient due to the low energy density of lithium – about 1% that of petrol and diesel. As a result, even as India creates infrastructure for EVs, it will have to retain its earlier infrastructure for petrol and diesel-fueled vehicles. Hydrogen has a higher energy density than petrol and diesel, and much higher than lithium, so it may be viable for use in heavy trucks.

II. Hydrogen Technology and Politics

Producing hydrogen from water via electrolysis is an old and well-understood process. Historically, the petroleum refining industry has produced hydrogen on an industrial scale for its own use and for other industries. The process, which involves reformulating methane derived from natural gas and coal gasification, requires no new infrastructure, and the cost per unit volume of hydrogen generated is low. But it releases carbon into the atmosphere. Climate-conscious industries and governments have pushed for alternatives to this "grey" hydrogen that are environmentally less harmful, though currently more expensive. In one approach, carbon emitted during the production of hydrogen from methane is captured and stored; gas produced this way is called "blue" hydrogen. The availability of numerous carbon capture and storage technologies (CCS) at commercial-ready technology readiness levels in the US and Europe is facilitating the transition from the long-running grey hydrogen-generating units to ones that produce this cleaner hydrogen.

A newer approach involves using renewable energy to produce hydrogen so that no carbon is emitted. Hydrogen produced this way is called "green" hydrogen. The transition from grey to green requires high levels of electrolysis instrumentation that can generate renewable hydrogen in commercial quantities including water (H_2O) electrolysers, ammonia (NH_3) electrolysers, and steam methane (CH_4) electrolysers. These technologies are at an early stage and are being developed by Norwegian and American firms.

Figure 1: The Differences between Grey, Blue and Green Hydrogen Technologies

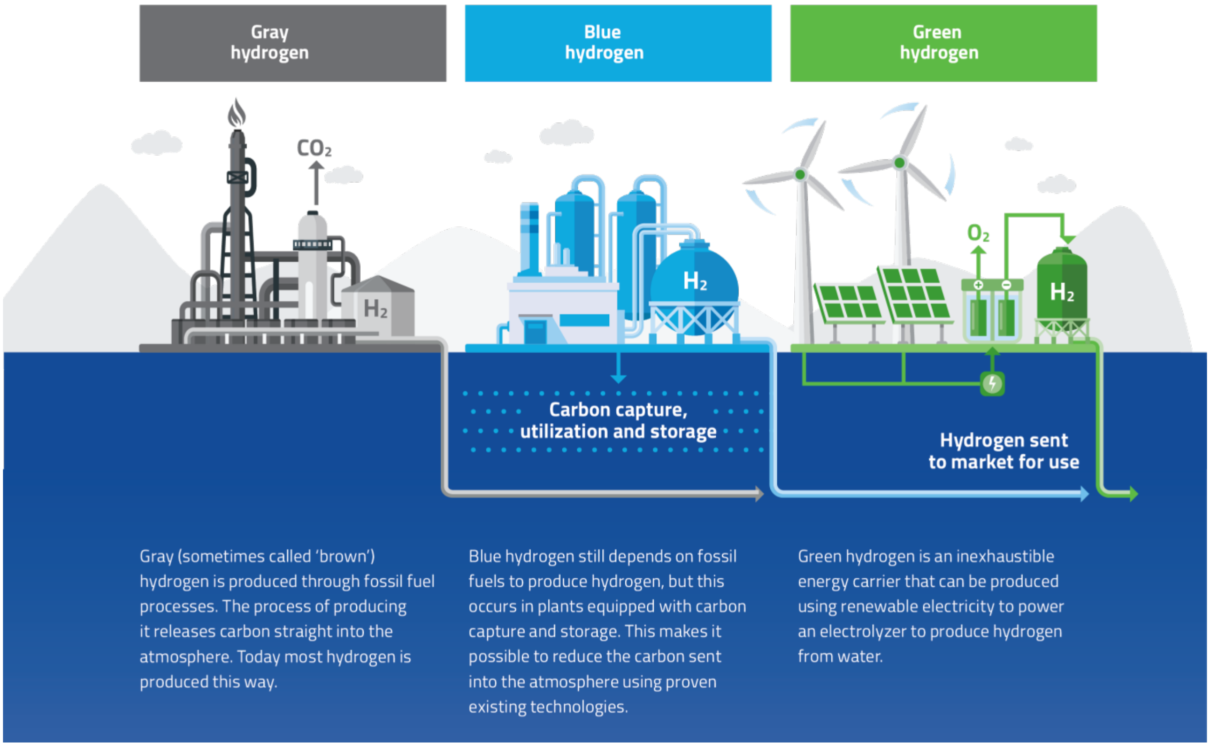
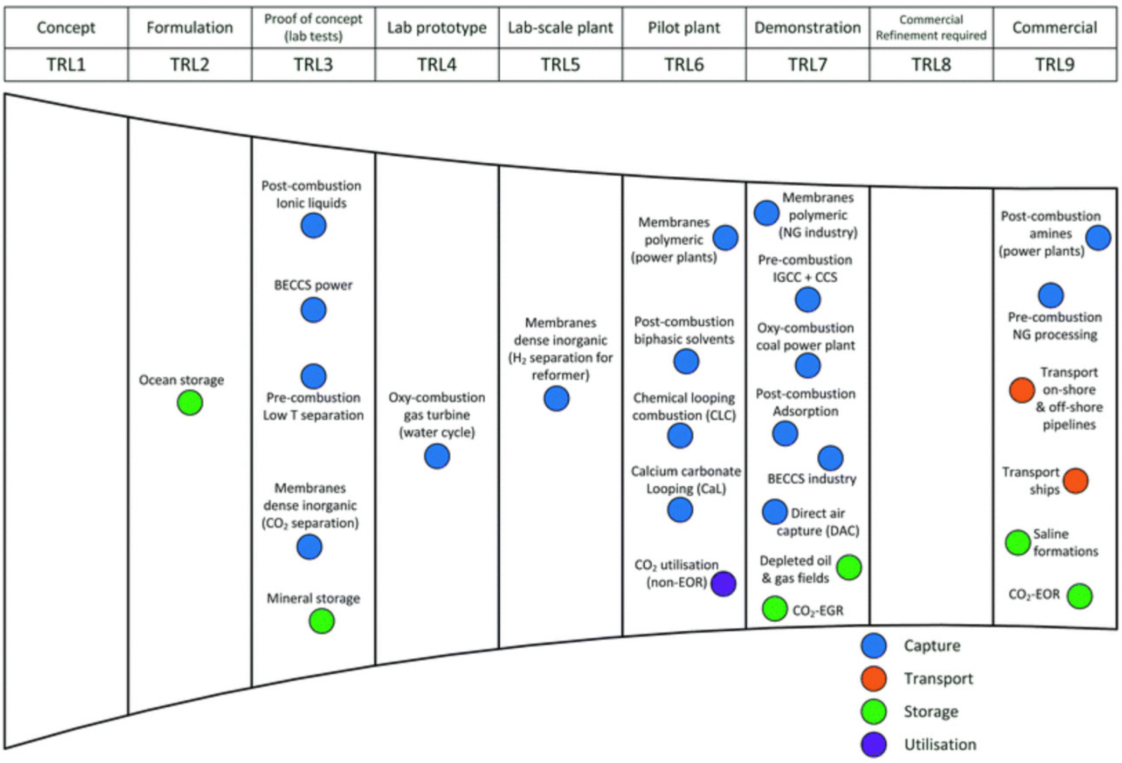


Figure 2: Current Status of Different CCS Technologies



The choice between blue and green hydrogen is a contentious issue. The oil, gas, and coal industries prefer blue hydrogen production because it is easier for them to add CCS technologies to their existing infrastructure and thus garner greater socio-economic acceptance in the era of decarbonization. But the clean energy (wind and solar) energy industries prefer green hydrogen since it potentially opens a new market for them.

For India, another factor plays a role: Blue hydrogen is produced from natural gas, which India imports. In light of India's interest in limiting its dependence on gas imports, this paper focuses on alternative business models for green energy producers.

III. Seeding a Market for Green Hydrogen

The largest drivers for building the hydrogen market are the carbon-pricing mechanisms and emission-trading systems that various national and subnational governments are adopting all over the world. In June 2021, about 64 carbon-pricing mechanisms had been implemented or scheduled globally, including 33 urban, national and regional carbon taxes and 31 emission trading systems (refer to Table 2). These mechanisms collectively discourage the use of carbon-intensive fuels and encourage the adoption of clean energy and fuel options across these geographies.

Table 2. Status of Carbon Tax and Emission Trading Systems Across Markets

CARBON TAX (CT)

Implemented	**Scheduled**	**Under Consideration**
Argentina		Senegal
United Kingdom		Ivory Coast
South Africa		
Baja California (Mexico)	Tamualipas (Mexico)	Jalisco (Mexico)
Zacatecas (Mexico)		
Namibia		

EMISSION TRADING SYSTEM (ETS)

Implemented	Scheduled	Under Consideration
Germany		Indonesia
Belgium		Turkey
Austria		Rio de Janeiro (Brazil)
Italy		Sao Paulo (Brazil)
Czechia		Thailand
Lithuania		
Greece		
Hungary		
Slovakia		
Croatia		
Bulgaria		
Romania		
Kazakhstan		
China		
South Korea		
Australia		
New Zealand		
Tokyo (Japan)		
Washington (US)		
California (US)		
Alberta (Canada)		
Saskatchewan (Canada)		
Quebec (Canada)		
Nova Scotia (Canada)		
Massachusetts (US)		

ETS + CT

Implemented	Scheduled	Under Consideration
Canada	Chile	Netherlands
Mexico	Colombia	
Portugal	Ukraine	
Spain	Japan	
France	Taiwan	
Switzerland	Oregon (US)	
Iceland	New York (US)	
Ireland	Connecticut (US)	
Poland	Manitoba (Canada)	
Estonia		
Finland		
Norway		
Sweden		
Slovenia		

For instance, the European Union Emission Trading System (EU ETS) allows trading of emission allowances between the largest emitters – ones collectively responsible for 50% of the total greenhouse gas emissions in the EU – so that there is considerable reduction in emissions at lowest costs without denting the European economy.[5] The EU ETS cap-and-trade system began in 2007, and in 2021 it entered Phase 4 where the annual linear reduction in emissions has become more stringent at 2.2% as compared to Phase 3, where the annual linear reduction was 1.74%.

In July 2021, the EU ETS made revisions designed to accommodate new means that will make emission reduction economically viable. In the new EU ETS proposal, the electrolyser-based hydrogen production will be eligible for ETS allowances. This inclusion is likely to extend to the transportation sector and other energy-generating facilities. The inclusion of hydrogen in EU ETS is in line with the European Commission's European Green Deal where the EU is aiming to build 40 GW of renewable hydrogen electrolysers and produce 10 million tonnes of renewable hydrogen indigenously.[6]

The precedents set by the EU ETS will have an impact on all other national and sub-national governments that have ongoing ETS mechanisms but have not revised them to make hydrogen eligible for allowances. Increasing stringency of ETS and similar carbon tax mechanisms will push the inclusion of hydrogen production, in terms of wattage and tonnage, for cap-and-trade. Since the largest emitters in any nation are by and large the transportation and energy industries, it is quite evident that their emphasis on hydrogen vehicles and green hydrogen will only grow.

4. Hydrogen as a Solution to India's Dependence on Lithium Imports for Electric Mobility

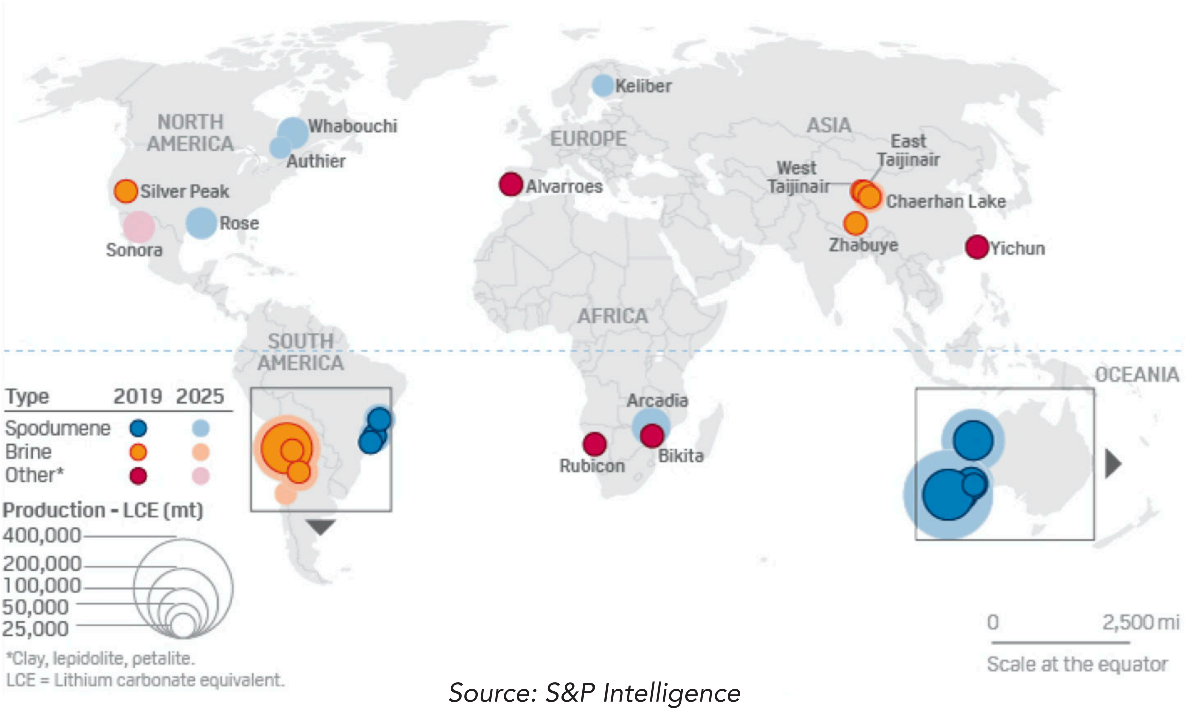
Electric vehicles are among the most significant alternative energy innovations. Companies such as Tesla have captured popular imagination – and also a big share of the capital flowing into green technology. Hydrogen-fuelled vehicles can be an alternative to EVs. EVs and HVs each have their technological advantages and disadvantages, and experimentation with the technologies is playing out around the world.

One major consideration for India in choosing between EV and HV will be the availability of lithium. India has negligible lithium reserves and will depend entirely on imports. Unlike oil, lithium is concentrated in a handful of countries, making the supply chain vulnerable. Moreover, it is not clear whether there is sufficient lithium available globally to move the auto sector to EVs.

Considering these disadvantages, India will benefit from a balanced energy strategy to develop a range of clean mobility options, including electric and hydrogen. Other countries, including the US, Japan, Germany, France and South Korea, are trying to do the same.

India is using its massive market and robust Make in India program to secure stable demand for lithium, cobalt, silicon metal and non-Rare Earth Elements (non-REEs), all of which are needed to manufacture batteries for electric vehicles. In 2019, three central public sector enterprises (CPSEs) – Mineral Exploration Corporation Limited, Hindustan Copper Limited and National Aluminium Company Limited – established a joint-venture company, Khanij Bidesh India Limited (KABIL), to secure supplies of these elements. Since then, KABIL has engaged with corresponding entities in Australia, South America's Lithium Triangle, and Africa to secure a steady supply of the needed elements from these regions. However, at the time of writing this paper, KABIL doesn't have any investments in natural resources.

Figure 3: Worldwide Lithium Reserves and Production



Source: S&P Intelligence

The lack of domestic, commercially viable and operational mines for these minerals is bound to create new and uncharted import-dependency for India – a situation that is difficult to manage without experience. The Geological Survey of India (Ministry of Mines) and Atomic Minerals Directorate for Exploration and Research (Department of Atomic Energy) have begun exploring new commercially viable lithium reserves within India's territorial limits. But even if the search is successful, the transition from reconnaissance surveys to mineral processing could take a very long time.

The immediate challenge is to overcome a dependency on imported lithium. On 11 February 2021, the Government of India mandated its science and technology agencies – NITI Aayog, Indian Space Research Organization, Defence Research Development Organization, Council on Scientific and Industrial Research, Indian Institutes of Technology, and the Ministries of Micro, Small and Medium Enterprises, Science and Technology, Heavy Industries, Road Transport and Highways, and Commerce – to undertake R&D on alternatives to lithium-ion BES (Battery Energy Storage) technologies such as metal-air, metal-ion and other potential technologies. IIT Hyderabad has been researching dual carbon batteries; IIT Madras is working on zinc-air, sodium-ion, and sodium-sulphur batteries; the Vikram Sarabhai Space Center has been working on potassium-ion batteries. The evolution of these low-technology, readiness-level alternatives will continue in the coming years.[7]

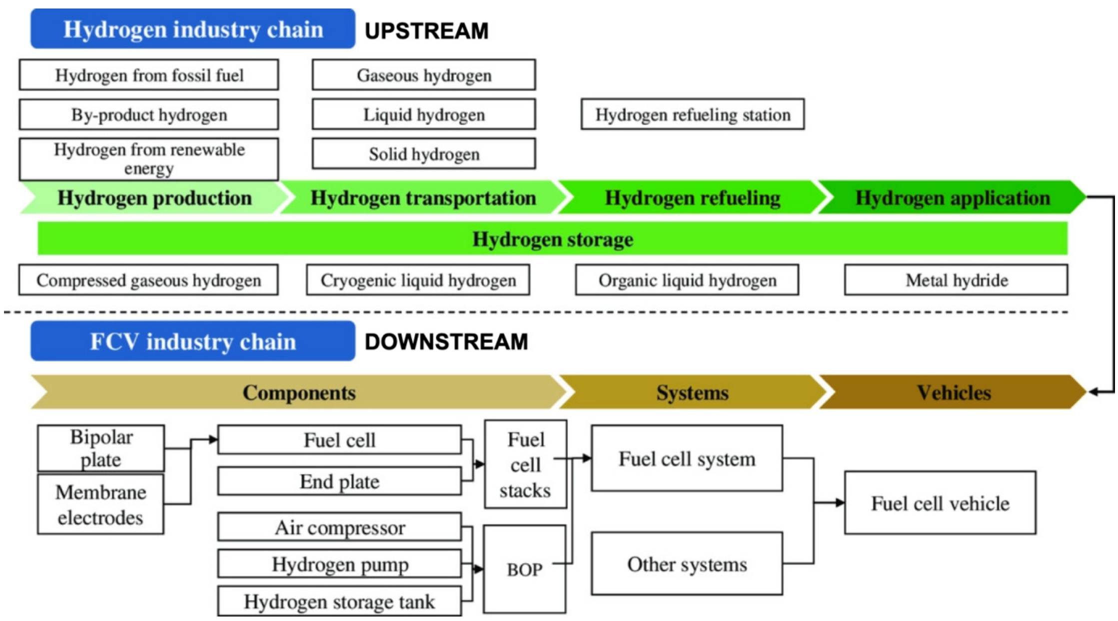
However, none of these EV options alone will enable India to attain its 2030 decarbonization goals that it committed to pursuing in the 2015 Paris Agreement.

Hydrogen-fuel vehicles offer a robust alternative to electric vehicles for two reasons:

First, automotive innovation worldwide has led to breakthroughs that are rapidly creating alternatives to the expensive REE- and platinum-consuming hydrogen fuel cell technologies. The newest and most promising innovation is a hydrogen internal combustion engine (ICE), which is a modified version of hydrocarbon-based engines.

A hydrogen ICE can operate with hydrogen-blended gas (up to 50% blending) or hydrogen-based, compressed natural gas along with pure hydrogen. The blending options are low-hanging fruits in the quest for decarbonized fuels that can be utilized expediently. The transition from Hydrogen Fuel Cell to Hydrogen ICE will simplify the downstream and will only need tweaking of the extant gas ICE to accommodate hydrogen as an alternative fuel.

Figure 4: The Upstream & Downstream Segments of the Hydrogen Ecosystem



Hydrogen-based internal combustion engines can drastically reduce the growing dependency on lithium, silicon metal, cobalt and REEs for electric-vehicle batteries, and therefore reduce import dependency. Hydrogen-CNG and hydrogen internal combustion engines can be used immediately to power buses, trucks, and industrial vehicles like forklifts.

5. Hydrogen as a 21st Century Fuel

Hydrogen is already an important industrial gas used for petroleum refining and production of fertilizers and steel. This section will focus on efforts directed towards the future:

1. Use of green energy for hydrogen production
2. Use of hydrogen in the transport sector

I. Investments in Green Hydrogen

A number of gigawatt-scale, green-hydrogen manufacturing facilities have been announced worldwide, but the largest green hydrogen plants that are currently operational, under construction or have been announced are small – in a range of 10-40 megawatts (MW). The green hydrogen from these projects is not necessarily destined for the transport sector; in many cases, it is meant for industrial applications. A facility in Taiwan (Table 1), for instance, will produce hydrogen for use in semiconductor manufacture. The oil industry, a major user and producer of hydrogen, is the key investor in some of these projects and also is involved in building hydrogen infrastructure. All the projects in this list are either operational, under implementation or planned for completion by 2024.

Table 3: Completed and Ongoing Green Hydrogen Projects

Project Name/ Location	Country	Electrolyzer Capacity (MW)	Production Capacity (Kg)	Status	Technology
FH2R, Fukushima[8]	Japan	20	100 kg/hr	Completed	
Bécancour, Québec[9]	Canada	20	8,200 kg/day	Completed	
Rheinland[10]	Germany	10	1,300 tons/yr	Completed	PEM
Lancaster, California[11]	U.S.		11,000 kg/day	Announced	
Tainan & Hsinchu[12]	Taiwan	25	450 kg/hr	Under Construction	
Wunsiedel[13]	Germany	8.75		Under Construction	
Masshylia[14]	France	40	5,000 kg/day	Announced	
Sardinia[15]	Italy	20		Announced	
Leuna[16]	Germany	24		Under Construction	PEM
GreenLab[17]	Denmark	24		Announced	
SEM-REV[18]	France			Announced	
Puertollan[19]	Spain	20		Under Construction	PEM
Frederecia[20]	Denmark	20		Under Construction	

Several other large, green-hydrogen projects have been proposed, but the "mega" projects are mostly on the drawing board and are a decade or more from implementation.

Table 4: Proposed Mega-Hydrogen projects

Project Name/ Location	Country	Capacity	Cost	Companies Invovled
NEOM hydrogen project[21]	Saudi Arabia	1.2 million tons of green ammonia per year	$7 billion	Air Products (US) & ACWA Power (KSA)
Asia Renewable Energy Hub	Australia	23 GW	$36 billion	AREH consortium
2 GW Green H2 Projec	UAE	2 GW		TAQA & Abu Dhabi Ports
HyNetherlands	Netherlands	100 MW (expansion planned)		Engie & Gasunie
Silver Fox	Italy	800,000 tons H2 (over 8 years)		Hydrogenics Europe, Meyer Burger, Ecosolifer, European Energy
H2morrow[23]	Germany	8.6 terawatt hours of hydrogen per year		Equinor & OGE
NorthH2[24]	Netherlands	4 GW (10+ GW by 2040)		Shell, Groningen Seaports Gasuine, Equinor
Black Horse[25]	Poland, Czechia, Hungary, Slovakia	320 tons green H2 per day	Euro 5.7 billion	

II. Use of Hydrogen in Transport

Industrial uses of hydrogen in the petroleum refining, fertilizer, steel and electronics industries are already well established. The use of hydrogen as a transport fuel is still at a nascent stage. Use of green hydrogen in these applications will displace petroleum-based fuels, helping bring down carbon dioxide emissions.

- **Hydrogen-Powered Forklifts**
  Developers often build experimental forklifts for material handling to try out promising new technologies. They are typically used in gated systems like ports, airports and warehouses. They can be served by captive infrastructure at a single point. Unlike cars and trucks, they don't need fuel stations spread across an entire region or route. Data published by the US Department of Energy indicates that by 2018, more than 21,000 forklift trucks were running on fuel cells in the US. Consumer-focussed companies that have large warehousing operations – for instance, Amazon, Coca Cola, FedEx, Nestle, P&G and WalMart – are amongst companies that have purchased or ordered fuel cell forklifts.[26]

- **Hydrogen in Heavy Vehicles**
  Electric two-wheelers and cars are already in use in almost all key markets globally. However, EV technology is not viable in heavier vehicles such as heavy-duty trucks, which account for a significant share of oil demand from the transport sector. But hydrogen-fuelled trucks, also called Fuel Cell Electric Vehicles (FCEVs) are more promising, as some global manufacturers are demonstrating:
  1. **Hyundai:** In July 2020, Hyundai shipped 10 of its XCIENT heavy-duty trucks to Switzerland. The company expects to deliver 1,600 trucks by 2025. The truck has significant capacity: it can pull a maximum load of 36 tonnes to a range of 400 kilometres on a 32 kg hydrogen fuel tank.[27]
  2. **Toyota-Hino:** In December 2020, Toyota delivered the first two FCEV-powered Class 8 heavy trucks to a customer in Los Angeles, with eight more scheduled to be delivered during 2021.[28]
  3. **Volvo-Daimler:** The two European automakers are competitors, but they formed a 50-50 joint venture in March 2021, with a capital of 1.2 billion Euros, intending to develop and commercialize fuel-cell systems for long-haul trucking.[29]

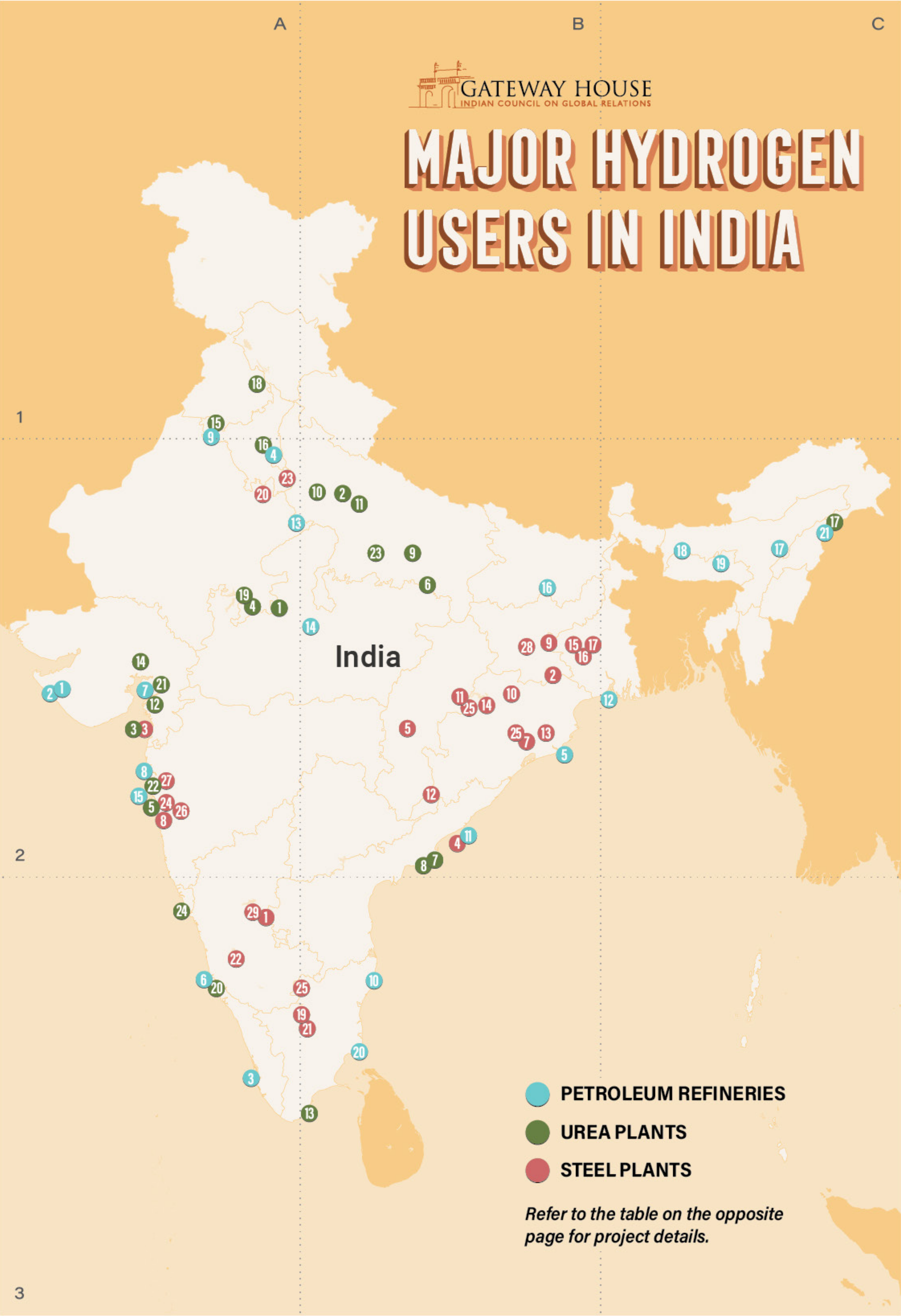
- **Hydrogen Locomotives**
  Electric locomotives are typically used on high traffic-density routes where engines don't need to carry fuel. On non-electrified tracks, diesel engines continue to be used worldwide, including in India. An electrical battery cannot carry the energy needed for railway applications, making hydrogen the only viable alternative to replacing diesel engines.

  The first train to run on hydrogen fuel-cell technology began operations in 2018 in Germany[30] and also completed a three-month test run in Austria.[31] Orders have so far come from Germany,[32,33] & France,[34] and Italy.[35] The trains are designed to replace diesel-run trains on non-electrified tracks.

  China is also conducting trials. In January 2021, China unveiled its first hydrogen fuel-cell hybrid locomotive, capable of 700 kW (940 HP) and running for more than 24 hours.[36] A Japanese consortium that includes Toyota and Hitachi is working on a hydrogen locomotive. In North America, Canadian Pacific Rail is planning to test a hydrogen train.

  Indian Railways is looking at hydrogen too. In 2020, it invited bids for a hydrogen-powered locomotive[37] for a special train;[38] the response to the tender is not yet known.[39]

MAJOR HYDROGEN USERS IN INDIA



PETROLEUM REFINERIES

Capacity: Million Tons Per Annum

NO.	NAME	COORD.	CAPACITY
01	Reliance Industries Ltd.	A2	63
02	Nayara Energy Ltd.	A2	20
03	Bharat Petroleum Corporation Ltd. (BPCL)	A3	15.5
04	Indian Oil Corporation Ltd.	A2	15
05	Indian Oil Corporation Ltd.	B2	15
06	ONGC-Mangalore Refineries & Petrochecmicals Ltd.	A3	15
07	Indian Oil Corporation Ltd.	A2	13.7
08	Bharat Petroleum Ccorporation Ltd. (BPCL)	A2	12
09	HPCL-Hindustan Mittal EenergyLtd.	A1	11.3
10	Chennai Petroleum Corporation Ltd.	B3	10.5
11	Hindustan Petroleum Corporational Ltd. (HPCL)	B2	8.3
12	Indian Oil Corporation Ltd.	C2	8
13	Indian Oil Corporation Ltd.	A2	8
14	BPCL-Bharat Oman Refineries Ltd.	B2	7.8
15	Hindustan Petroleum Corporational Ltd. (HPCL)	A2	7.5
16	Indian Oil Corporation Ltd.	B2	6
17	Numaligarh Refineries Ltd.	C2	3
18	Indian Oil Corporation Ltd.d	C2	2.35
19	Indian Oil Corporation Ltd.	C2	1
20	Chennai Petroleum Corporation Ltd.	B3	1
21	Indian Oil Corporation Ltd.	C2	0.65

UREA PLANTS

Capacity: Million Tons Per Annum

NO.	NAME	COORD.	CAPACITY
01	Chambal Fertilizers and Chemicals Ltd. Gadepan 1, 2, 3	A2	3.4
02	IFFCO Aonla 1, 2	B2	2.89
03	Krishak Bharti Cooperative (Kribhco)	A2	2.19
04	National Fertilizers Limited Vijaipur 1, 2	A2	2.06
05	Rashtriya Chemicals and Fertilizers Ltd.	A2	2
06	IFFCO Phulpur 1, 2	B2	1.7
07	Nagarjuna Fertilizers and Chemicals Ltd. Kakinada 1, 2	B2	1.5
08	Matix Fertilizers and Chemicals Ltd.	B2	1.3
09	Indo Gulf Fertilisers	B2	1.2
10	Yara Fertilizers	B2	1.2
11	Kribhco Fertilizers Ltd.	B2	0.86
12	Gujarat Narmada Valley Fertilizers and Chemicals Ltd.	A2	0.63
13	Southern Petrochemical Industries Corporation	B3	0.62
14	IFFCO Kalol	A2	0.60
15	National Fertilizers Ltd.	A1	0.51
16	National Fertilizers Ltd.	A2	0.51
17	Brahmaputra Valley Fertilizer Corporation Limited Namrup 2, 3	C2	0.51
18	National Fertilizers Ltd.	A1	0.47
19	Shriram Fertilizers and Chemicals	A2	0.37
20	Mangalore Chemicals and Fertilizers Ltd.	A3	0.37
21	Gujarat State Fertilizers and Chemicals Ltd.	A2	0.36
22	Rashtriya Chemicals and Fertilizers Ltd	A2	0.33
23	Kanpur Fertilisers & Cements Ltd.	B2	
24	Zuari Agro Chemicals Ltd.	A3	

STEEL PLANTS

Capacity: Million Tons Per Annum

NO.	NAME	COORD.	CAPACITY
01	JSW Vijayanagar Steel Plant	A3	12
02	Tata Steel	B2	11
03	Essar Hazira Steel Plant	A2	10
04	Vizag Steel Plant	B2	6.3
05	Bhilai Steel Plant (SAIL)	B2	6
06	Jindal Steel Plant	B2	6
07	Tata Steel BSL	B2	5.6
08	JSW Dolvi Steel Plant	A2	5
09	Bokara Steel Plant (SAIL)	B2	4.61
10	Rourkela Steel Plant (SAIL)	B2	3.8
11	Jindal Steel Plant	B2	3.6
12	NMDC Steel Plant	B2	3
13	Tata Steel	B2	3
14	Bhushan Power & Steel Ltd	B2	3
15	IISCO (SAIL)	B2	2.5
16	Durgapur Steel Plant (SAIL)	B2	2.2
17	Alloy Steel Plant (SAIL)	B2	2.2
18	Monnet Ispat & Energy Ltd	B2	1.5
19	JSW Salem Steel Plant	B3	1
20	Asian Colour Coated Ispat	A2	1
21	Salem Steel Plant (SAIL)	B3	0.18
22	Visvesvaraya Iron and Steel Plant (SAIL)	A3	0.18
23	Tata Steel BSL	A2	
24	Tata Steel BSL	A2	
25	Tata Steel BSL	B3	
26	Essar Steel Pune Facility	A2	
27	JSW Vasind Works	A2	
28	Patratu Jindal Steel Plant	B2	
29	Hospet Steels (Kalyani)	A3	

- **Hydrogen-Powered Marine Vessels**
  International shipping is a significant contributor to global greenhouse gas and particulate emissions because ships use heavy oil as fuel. As a result, there is interest in using hydrogen as a marine fuel.

  The underwater arm of the German Navy is an early user. Submarines have always relied on electric batteries for underwater propulsion, and with the exception of nuclear craft, still do. However, their underwater endurance is limited because they use batteries with low energy density. A group of technologies known as Air Independent Propulsion (AIP) allows submarines to remain submerged for extended durations. Some AIP technologies are based on hydrogen fuel cells; the European armed forces are early innovators and adaptors.

  Germany's Type 212 submarines use hydrogen fuel cells as a part of their AIP systems.

  Norway is currently working on multiple hydrogen-powered marine vessels:

  1. **MF Hydra:** This 82-meter-long boat, which can carry 299 passengers and 80 cars, will run on hydrogen fuel cells.[40]
  2. **Hydrogen-Powered Cargo Ship:** Norwegian shipping company EgilUlvanRederi has a contract to build and operate the world's first hydrogen-powered cargo vessel on behalf of two of its clients.[41]

III. Hydrogen in Power Generation

South Korea is a leader in this technology and has an installed capacity of 508 MW Hydrogen power. In October 2021, a 78.96 MW power plant – the Shinincheon Bitdream Fuel Cell Power Plant was commissioned in South Korea. This plant runs entirely on hydrogen fuel cells.[42] The world's second-largest hydrogen-fired power plant, the 76.8 MW Western Incheon Fuel Cell Power Plant, is also in South Korea. Doosan Fuel Cells has provided fuel cells for both of these projects, and for 433 MW of the installed 508 MW capacity in South Korea. These plants will run on hydrogen coming from conventional (grey) sources for now. They provide opportunities for hands-on experience in using hydrogen for power generation and understanding the challenges that it poses. These power plants will serve as a ready market for green hydrogen once production starts in Korea. South Korea seems more focused on the downstream use of hydrogen than on the production of green hydrogen.

Norway is a part of many of the ongoing innovations in the green hydrogen economy, from trucks to ships to the production of hydrogen.

IV. Green Hydrogen Pioneers and Leaders: The Norway Way

Norway has been a pioneer in green hydrogen, and a Norwegian company, Nel Hydrogen, is the world's largest manufacturer of electrolyzers. Nel has the capacity to produce 500 MW of electrolysers annually, and the company has set a public target of bringing down the cost of green hydrogen to $1.5/kg by 2025.[43] Norway already has a small fleet of hydrogen-fuelled trucks,[44] and there are plans to introduce ships running on the hydrogen. It uses hydropower to produce hydrogen from water, and it expects to become an exporter of hydrogen instead of oil and natural gas to the rest of Europe, instead of the oil and natural gas that it currently exports.

Norway's leadership in this field is partly historical. The country has abundant hydropower and began large-scale electrolysis of water to produce hydrogen in the 1920s. Its first hydrogen-production facility was built in 1928. The plant was large by modern standards and used hydroelectricity[45]. A second large facility to produce hydrogen from hydroelectricity was built in the 1950s. Norway's oil wealth and prosperity have played a role in its attitude towards green energy. As countries prosper, they also tend to clean up their energy mix. The country's sovereign wealth fund, with over $1 trillion of assets, announced in 2019 that it wouldn't be investing in fossil fuel projects in other countries.

Worldwide, most hydrogen energy and fuel technologies initiatives do not take place in isolation. Different companies and institutions operate in different parts of the hydrogen value chain. These institutions often form transnational hydrogen coalitions or alliances to share research and experience. Domestically, the industries prefer not to create multiple alliances but stay with one coalition. This helps them resolve challenges involving the national and sub-national governments, smoothens policymaking and advocacy, and enhances profits without cannibalizing the domestic growth of the hydrogen industry. Such national alliances (Table 5) comprise participants from the petroleum, industrial gas, automotive, specialty chemicals, advanced materials, heavy and precision engineering, banking and insurance, software, and clean energy industries.

Table 5: Various National Hydrogen Industry Alliances/Coalitions/Councils

Country	Name of Alliance of Hydrogen Industries
Japan	Japan Hydrogen Association
China	China Hydrogen Alliance
South Korea	K-Hydrogen Council
United Arab Emirates	Abu Dhabi Hydrogen Alliance
France	France Hydrogene
Latvia	Latvian Hydrogen Association
European Union	European Clean Hydrogen Alliance
England	North West Hydrogen Alliance
Australia	Australian Hydrogen Council
Germany	Clean Energy Partnership
Italy	Italian Association for Hydrogen and Fuel Cells
Spain	Spanish Hydrogen Association
Austria	Wasserstoffinitiative Vorzeigeregion Austria Power & Gas
Brazil	Brazilian Hydrogen Association

Country	Name of Alliance of Hydrogen Industries
Canada	Canadian Hydrogen and Fuel Cell Association
United States	Fuel Cell and Hydrogen Energy Association
Russia	National Association of Hydrogen Energy
India	India Hydrogen Alliance
Netherlands	Netherlands Hydrogen & Fuel Cell Association
Denmark	Hydrogen Denmark
New Zealand	New Zealand Hydrogen Association
Ireland	Hydrogen Ireland
Ukraine	Ukrainian Hydrogen Council
Turkey	National Hydrogen Association - Turkey

International and transnational hydrogen industry alliances play an important role in galvanizing international consensus on financing, R&D, technology standardization and deployment of hydrogen energy and fuel technologies. Some alliances – for instance, the MENA (Middle East and North Africa) Hydrogen Alliance, Hydrogen Europe or the African Hydrogen Partnership – are specific to certain geographies . Some of the leading international hydrogen alliances with their prominent and other members are below (Table 6).

6. Business Models For Hydrogen

I. Hydrogen as Industrial Gas

Hydrogen is used in the petroleum refining, steel and fertilizer industries. Most hydrogen is produced with natural gas (76%) or coal (23%).[46] As the use of coal, and to a lesser extent, natural gas, comes under pressure due to environmental concerns, India's large base of plants in these industries represents a ready market for green hydrogen in addition to the demand for other purposes such as transport. (See Figure 5: Map of India's Hydrogen Users).

This suggests that, unlike some other emerging technologies (including electric vehicles), green hydrogen production facilities will not become stranded assets. Drivers for the shift to green hydrogen may come from the regulatory/environmental space rather than commercial considerations – as was initially the case for renewable energy.

- **Petroleum Industry**

  The oil sector around the world, especially major corporations Exxon,[47] Shell[48] and Chevron[49] are facing pressure from activists to reduce their carbon footprint. The petroleum refining industry will likely drive the shift towards green hydrogen. It is the most profitable of the three industries that use hydrogen, followed by steel, while the fertilizer sector is weaker, requiring government support. India's oil companies are moving ahead, too:

  1. State-run Indian Oil Corp. (IOC) is planning to build India's first green hydrogen plant at its petroleum refinery in Mathura.[50] The refinery is close to the Taj Mahal, an added motivation to pursue clean technologies. In June 2021, IOC awarded a tender for 15 fuel-cell buses to Tata Motors.[51] These buses, which will largely be used by IOC for real-world testing in the Delhi National Capital Region, will be run on hydrogen produced and dispensed by IOC.
  2. During its 2021 Annual General Meeting, Reliance Industries Limited announced it will set up a giga-factory, an electrolyzer to produce green hydrogen, at its Jamnagar refinery. The company also proposes to build a fuel cell factory at Jamnagar.[52] RIL is a major exporter of refined petroleum products and may be sensitive to pressures faced by global oil majors. The same is true of Saudi Aramco, with which Reliance is exploring a partnership; Saudi Arabia itself is evaluating large investments in green hydrogen.
  3. Hindustan Petroleum, also a public sector oil company, is planning to set up a green hydrogen pilot project in one of its refineries – replacing hydrogen produced from petroleum-derived naphtha at present.

- **Steel Industry**

  Public sector Steel Authority of India Limited (SAIL) and private sector Tata Steel are the largest steelmakers in India. Tata Steel also has a large overseas presence, with facilities in the U.K. and the Netherlands that it obtained through its acquisition of Corus in 2007.

  In 2018, Tata Steel proposed setting up a 100 MW green hydrogen plant at one of its operations in the Netherlands.[53] Any move Tata makes to produce green hydrogen in India is likely to happen only after that project is operational.

- **Other Industries**

  The renewable energy industry could move into green-hydrogen production, motivated by a need to diversify its customer base beyond state-run power distribution companies.

  1. State-run National Thermal Power Corporation Limited (NTPC) will implement a pilot green hydrogen mobility project in Leh, Ladakh and Delhi, with five buses and five cars running on hydrogen-powered fuel cells in each location.[54]
  2. ACME Solar, a renewable energy producer, has signed an MOU with Lhyfe of France to produce green hydrogen in Europe and India.[55] ACME has a pilot plant producing green hydrogen in Rajasthan.[56]
  3. JSW Green Energy, a subsidiary of JSW Energy and a part of the OP Jindal Group, which also has interests in steel, has recently signed an agreement with Fortescue Future Energies of Australia to collaborate on the production of green hydrogen for industrial use.[57]

II. Hydrogen as a natural gas additive

Hydrogen can be blended with natural gas, and the mixture can be used in the pre-existing natural gas infrastructure. For instance, in some parts of the U.K., a mixture with up to 20% hydrogen content has been used in the home-piped gas network with no noticeable impact on performance.[58] India is currently working on supplying piped gas to households and industry in more than 100 cities – offering another market for green hydrogen. Indraprastha Gas (Delhi NCR), Mahanagar Gas (Mumbai) and Gujarat Gas (Gujarat) are the three biggest players in the city gas business.[59]

III. Start-ups based on hydrogen fuel-cell technology

A number of start-ups, particularly in the US, are trying to find a niche in the potential hydrogen market by producing the gas and fuel cells to convert hydrogen to electricity or motive power, including for marine transport or even aviation (see Annexure A). So far, India has not seen similar activity, but given the recent boom in venture funding, start-ups and IPOs, it could in the near future. A detailed look at some of these business models can be found in Annexure I.

7. Policy Suggestions for a Hydrogen Economy

Green hydrogen as a large-scale energy alternative is still at an experimental stage worldwide. Most production facilities are at a pilot scale, and research on its use as an automobile fuel or in power generation is still ongoing. Therefore, policy recommendations at this stage must aim to encourage research and trials for technologies, infrastructure, and business models. Early investments made in technologies that are not fully established can result in stranded, unproductive assets, so it is important to keep the failures small.

1. Mandate green hydrogen blending for existing users

The least disruptive place to start adopting green hydrogen is existing industrial users of hydrogen: petroleum refining and the fertilizer and steel industries. Hydrogen, whether produced using green or grey technologies, is the same gas. These industries already have the infrastructure required to handle and use it. So a market for green hydrogen manufacturing equipment and construction services can be created without requiring massive downstream investments.

For the foreseeable future, green hydrogen will not be financially viable. Government policies can require that 5% of the hydrogen used by petroleum refineries be green hydrogen. This is similar to the ethanol blending with petrol[60] that has been mandated by the government.

The policy has to be technology or source-agnostic. Companies can choose to produce green hydrogen themselves or purchase the gas from vendors. With several large-scale hydrogen users now inside urban areas, a blending mandate can facilitate the emergence of independent green hydrogen producers.

2. Extend the green hydrogen blending mandate to CNG

Once the technical and financial challenges of green hydrogen are better understood, the blending mandate can be extended to compressed natural gas. India already has a compressed natural gas (CNG) program across 100 cities. More than 3.3 million vehicles in India use CNG as fuel, while 5 million households get piped natural gas at home. Hydrogen and CNG can be blended up to 20-80 mixture and used in existing internal combustion engines running on CNG.

As with petroleum refining, a blending mandate will require limited investments in downstream CNG infrastructure. Such a program can be initiated in a small number of cities, and then expanded gradually as a better understanding of technical and commercial challenges emerges.

3. Use green hydrogen for gated infrastructure

One problem of introducing a new class of vehicles that use a new fuel – whether CNG, electricity or hydrogen – is refuelling them. Petrol pumps are ubiquitous, and the infrastructure has been built up over a century. Creating a similar distribution system in short order for hydrogen will be difficult. Consumers will be reluctant to buy new energy vehicles if refuelling is a problem, while establishing a network of refuelling stations for new energy vehicles will not be feasible unless there is a large fleet on the roads.

Building fleets of hydrogen-fuelled vehicles in gated infrastructure for captive use is a good starting point. Airports, ports and warehouses use a large number of vehicles such as forklifts, cranes, trucks, tractors, and passenger vehicles. Many, if not all of these have options that run on hydrogen fuel cells. Each such application can use hundreds of vehicles, creating demand which will allow manufacturers to bring vehicles that use hydrogen fuel cells into the market.

4. Extend green hydrogen blending to power generation

Gas-fired power plants will be needed to balance the intermittency of renewable energy. Using renewable energy to create hydrogen, and then burning it to produce electricity when renewable energy generation falls, is how a net-zero system will ideally work.

India has approximately 25,000 MW of natural gas-fired power plants, which were set up with the expectation of cheap, domestically produced natural gas. Many are now idle, while the remainder operate at a fraction of their capacity. Some of these plants can start using green hydrogen blended with natural gas as fuel. Power is a relatively low-value product for green hydrogen, though. So this use will come after higher-value applications have been exhausted.

5. Create specialist corporations for green hydrogen

The Indian government set up energy giants such as Indian Oil, ONGC, Gail, NTPC and Petronet LNG to implement large scale projects and infrastructure for which there was limited private sector interest. Similarly, city gas projects in Delhi and Mumbai were spearheaded by Indraprastha Gas Limited and Mahanagar Gas Limited. The existing energy majors are behemoths with complex business operations. Hydrogen cannot be a core focus area for them. Establishing specialised companies with a clear focus is a good way to get new projects off the ground, and this approach can be repeated for green hydrogen.

A model can be Petronet LNG, which has public sector companies (IOC, BPCL, ONGC, Gail) as shareholders with a combined stake capped at 50% to give the company more operational freedom. A similar entity (say, Indian Hydrogen Corporation Limited) can be created to invest in and implement green hydrogen projects. IHCL also can work with the private sector as a partner for hydrogen projects, as needed.

6. Involve the start-up, venture capital and private equity community

India's tech start-up ecosystem is a vibrant part of the economy., with over 60 unicorns –start-ups worth more than US$1 billion. Some of these such as Zomato, PayTM and PolicyBazar have already listed, while others are the in the queue. The ecosystem has been enabled by a mix of factors – entrepreneurs with ideas, investors willing to back those ideas and optimism around India's economy, among others. Many of these companies were able to find support from angel investors, venture capital and private equity backers. Involving this ecosystem in the green hydrogen push can be a powerful driver for growing this sector.

Having venture funds and private equity funds with a specific focus on green hydrogen can make it easier for entrepreneurs with new ideas to get funding and achieve scale. Stakeholders with an interest in green hydrogen – energy companies, infrastructure operators and automobile companies – can be brought together to set up a venture fund and a private equity fund focused on green hydrogen start-ups. Since many energy companies are owned by the government, it will be a partner in such a fund. However, the government's stake has to be kept below 50%, so that the fund doesn't become a public-sector enterprise.

Annexure I

Plug Power

Share Price	$31.5 (11 June, 2021)
Market Capitalization	$ 18.43 billion

Source[61]

Plug Power describes itself as "…a global leading provider of comprehensive hydrogen fuel-cell turnkey solutions. Plug Power has deployed more than 40,000 fuel cell systems, designed and built 110 refuelling stations that dispense more than 40 tons of hydrogen daily, and is a technology leader in green hydrogen solutions via electrolysis."

In January 2021, Plug Power formed HYVIA, a joint venture with Renault that will operate in France. HYVIA will build light commercial vehicles that run on fuel cells. It also will build hydrogen charging stations and will ensure the supply of green hydrogen to them.[62]

In June 2021, Plug Power announced it is setting up a green-hydrogen plant in the US (Camden County, Georgia) powered by renewable energy. This plant will produce 15 tons of hydrogen per day using renewable energy. The capital expenditures for the plant total $84 million.[63]

Ballard Power Systems

Share Price	$17.11 (16 June, 2021)
Market Capitalization	$5.08 billion

Source[64]

Ballard provides hydrogen fuel cells for heavy-duty trucks, trains and marine vessels.[65] The company has joint ventures with Weichei (China), Mahle (Europe) and Canadian Pacific (North America) for developing fuel cells for different applications. Ballard Fuel modules will be used in Canadian Pacific's hydrogen locomotive program.[66]

Bloom Energy

Share Price	$24.29 (16 June, 2021)
Market Capitalization	$4.2 billion

Source[67]

Bloom Energy was founded by KR Sridhar, who worked on NASA's Mars Exploration program. The company's core technology is based on research done by its founders on using electricity generated by a solar panel to produce fuel and oxygen on Mars for NASA. Bloom Energy Servers reversed this process by taking in fuel and air to generate electricity. Bloom is capitalizing on this technology by taking terrestrial renewable power and producing hydrogen using solid oxide electrolyzers.[68]

In May 2021, Bloom Energy announced an agreement with the Idaho National Laboratory to explore the use of nuclear power to generate hydrogen using Bloom's solid oxide, high-temperature electrolyzer.[69] Bloom is producing solid oxide fuel cells for South Korea in collaboration with SK Energy (a South Korean firm).[70]

Ceres Power Holdings

Share Price	GBP 992 (15 June, 2021)
Market Capitalization	GBP 1.89 billion

Source[71]

Ceres is a UK based fuel cell technology company whose work is based on research coming out of the Imperial College, London.[72] Its biggest shareholders are Weichai Power (China, State-owned, 19.94%) and Robert Bosch Gmbh (Germany, 17.75%).[73]

ZeroAvia

This is a U.S. and U.K.-based company trying to develop hydrogen-powered technology for short-haul (300-500 miles) flights. In September 2020, ZeroAvia carried out the world's first hydrogen fuel-cell powered flight,[74] powering a six-seat aircraft that flew up to 1,000 feet.[75] Because of its higher energy density, hydrogen can match fossil fuels in powering aircraft in range. However, carrying liquefied or gaseous hydrogen at high pressure on board an aircraft will remain a major challenge.

Five T Hydrogen Fund

This is a 1 billion euro infrastructure fund set up to invest in hydrogen-only projects. Plug Power, Chart Industries and Baker Hughes are the anchor investors.[76]

Annexure II

Table 6: Various International/Transnational Hydrogen Industry Alliances/Coalitions/Councils

Name of Inter/Transnational Hydrogen Alliances	Prominent Members	Other Crucial Members
MENA Hydrogen Alliance	Dii Energy (UAE)	ACWA Power (Saudi Arabia) State Grid Corporation of China (China)
Green Hydrogen Catapult	ACWA Power (Saudi Arabia) CWP Renewables (Australia) Envision Group (China) Iberdrola (Spain) Ørsted (Denmark) Snam (Italy) Yara (Norway)	
Hydrogen Europe	NEL Hydrogen (Norway) Vattenfall (Sweden)	Latvian Hydrogen Association (Latvia) France Hydrogene (France) Toyota (Japan) CNH Industrial (Netherlands) Airbus (France) Salzgitter (Germany) Equinor (Norway) Helbio (Greece) H2Energy (Switzerland) Gasunie (Netherlands)
Renewable Hydrogen Alliance	Southern California Gas Company (USA) Renewable Hydrogen Canada (Canada) Scottish Hydrogen & Fuel Cell Association (Scotland)	
African Hydrogen Partnership	AngloAmerican (United Kingdom) HDF Energy (France) Port of Rotterdam (Netherlands) RTS Africa Group (South Africa) Hydrox Holdings (South Africa) Hydroma (Canada) Hypowa (United Kingdom) Sable (Zimbabwe) Mobility Africa Energy (South Africa) Cheranna Energy (Scotland)	

Name of Inter/Transnational Hydrogen Alliances	Prominent Members	Other Crucial Members
Clean Energy Ministerial Hydrogen Initiative (International Energy Agency)	Australia Austria Brazil Canada Chile China Costa Rica European Commission Finland Germany India Italy Japan Netherlands New Zealand Norway Portugal Russia Saudi Arabia South Africa South Korea United Kingdom United States	
Hydrogen Council	3M Company (USA) ADNOC (UAE) Airbus (France) Air Liquide (France) Air Products (USA) Alstom (France) AngloAmerican (UK) Aramco (Saudi Arabia) Audi (Germany) BMW Group (Germany) Bosch (Germany) British Petroleum (UK) CF Industries (USA) Chemours (USA) CMA CGM (France) CHN Energy (China) CNH Industrial (Netherlands) Cummins (USA) Daimler (Germany) eDF (France) ENEOS Corporation (Japan)	AFC Energy (United Kingdom) AVL List GmbH (Austria) Baker Hughes (USA) Ballard Power Systems (Canada) Black & Veatch (USA) Bureau Veritas (France) Cellcentric GmbH (Germany) Chart Industries (USA) Chevron (USA) Clariant (Switzerland) Delek (USA) Elring Klinger (Germany) Enbridge Inc. (Canada) Faber Cylinders (Italy) Fortescue Metal Group (Australia) Galp (Portugal) Gore (USA) Hexagon Purus (Norway) Howden (UK) Iljin Composites (South Korea) Indian Oil (India)

Name of Inter/Transnational Hydrogen Alliances	Prominent Members	Other Crucial Members
	Engie (France) Equinor (Norway) Faurecia (France) General Motors (USA) Great Wall Motors (China) Honda (Japan) Honeywell (USA) Hyundai (South Korea) Iwatani (Japan) Johnson Matthey (United Kingdom) Kawasaki (Japan) Korea Gas Corporation (South Korea) Linde (Germany) Michelin (France) Microsoft (USA) Mediterranean Shipping Company (Switzerland) Plastic Omnium (France) SABIC (Saudi Arabia) Sasol Chemicals (South Africa) Schaeffler (Germany) Shell Petroleum (Netherlands) Siemens Energy (Germany) Sinopec (China) Solvay (Belgium) ThyssenKrupp (Germany) Total Energies (France) Toyota (Japan) Uniper (Germany) Weichai (China) John Wood Group (Scotland)	Itochu Corporation (Japan) John Cockerill (Belgium) Komatsu (Japan) Liebherr (Germany) Mahle (Germany) MAN Energy Solutions (Germany) Mann +HummelGruppe (Germany) Marubeni (Japan) McDermott (USA) McPhy (France) Mitsubishi Corporation (Japan) Mitsubishi Heavy Industries (Japan) Mitsui & Co. (Japan) Nel Hydrogen (Norway) NGK Spark Plugs (Japan) Nikola Corporation (USA) NYK Line (Japan) Parker Hannifin Corporation (USA) Petronas (Malaysia) Plug Power (USA) Port of Rotterdam (Netherlands) Power Assets Holdings Ltd. (China) Refire (China) Reliance Industries (India) Sinocat (China) SinoHytec (China) Sinoma Science & Technology (China) Snam (Italy) Southern California Gas Company (USA) Sumitomo Corporation (Japan) Technip Energies (France) Tokyo Gas (Japan) Toyota Tsusho (Japan) True Zero (USA) TÜV SÜD (Germany) Royal Vopak (Netherlands) Umicore (Belgium) Antin Infrastructure Partners (France) Barclays (United Kingdom) BNP Paribas (France) CréditAgricole (France) FiveT Hydrogen (Switzerland) GIC (Singapore) John Laing (United Kingdom) Mubadala (UAE) Natixis (France) Providence Asset Group (Australia) Sumitomo Mitsui (Germany) SocieteGenerale (France)

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